Stellar Students - Real Research in the Classroom

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Abstract

Peter Hatfield and students from the **Institute for Research in Schools** describe their latest results and describe how school students are contributing to real research.

When science is studied at the undergraduate level, we understand that learning without the connection to contemporary research can be uninspiring and doesn't give students experience in tackling unfamiliar problems. Undergraduate and Masters projects typically have an element of original research and many university departments offer summer undergraduate research projects to give these opportunities. Science education in secondary schools and sixth forms conversely often does not have this connection - the Institute for Research in Schools wants to change that. Founded in 2016, the aim of the institute is to let school students do real scientific research, and has projects spanning physics, chemistry, biology and social sciences in more than a hundred schools across the country.

The key aims of IRIS are:

1. To increase the number of young people and teachers who engage with STEM research at school in a way that raises aspiration, participation and attainment so that more young people, especially those from disadvantaged groups, continue with careers in STEM.
2. To establish within the teaching profession the model of the 'teacher scientist' as opposed to the science teacher so that a role within a school of Leader in STEM research and development is integral to the delivery of STEM Education in the school.
3. To enable teachers to be connected as key partners in STEM research with Universities, Industry and Research Councils and so retain them in the profession.

IRIS want to make research a key element of learning STEM such that both the teacher and student are contributing, valued members of the scientific community.

First Results from LUCID

LUCID (the Langton Ultimate Cosmic ray Intensity Detector) is a payload on the technology demonstration satellite TechDemoSat-1 (TDS-1, see figure 1), and is one of IRIS' flagship projects. It was proposed by school students for a British National Space Centre (now UK Space Agency) competition for students to design an experiment to go into space. The project started in 2008, and grew out of a school visit to CERN where students had a talk from Michael Campbell, Spokesperson for the Medipix Collaborations. Medipix detectors are a family of radiation detectors developed at CERN that had been used in the LHC and in medical applications - but never in space! The proposal was to use Medipix detectors as a radiation and cosmic ray monitor in orbit and continued to develop as a collaboration between Langton Star Centre secondary school student researchers, the Medipix Collaboration, and Surrey Satellite Technology Limited (SSTL), who built both LUCID and TDS-1. Much of the subsequent operations, data management and analysis were led by secondary school researchers through IRIS, with support from SSTL (spearheaded by David Cooke, Project Engineer) and the Medipix collaboration. There have been over a hundred students work on LUCID to date. Over the last year I supported three sixth form students (Will Furnell, Abhishek Shenoy and Elliot Fox) who had worked on LUCID to publish their work in a peer-reviewed journal; guiding them through writing their work up and the submission process, with the science completely proposed and carried out by themselves. A few months ago it was accepted in *Advances in Space Research* (Furnell et al., 2018), a credit to the huge amounts of work by the students over many years.

LUCID is part of the TDS-1 Space Environment Suite, which also includes the Miniature Radiation Environment and effects Monitor (MuREM), the Charged Particle Spectrometer (ChaPS) and the Highly Miniaturized Radiation Monitor (HMRM). TDS-1 launched on 8 July 2014 (15:58:28 UTC) on a Soyuz-2-1b launch vehicle with Fregat-M upper stage from the Baikonur Cosmodrome in Kazakhstan, into a 635 km, 98.4° Sun-synchronous orbit. Data collection ceased on the 4th July 2017, and at some point in the medium-term TDS-1 will be deorbited by the Icarus-1 Cranfield Drag Augmentation System de-orbiter, Hobbs et al. (2013), which will over the next 25 years guide the spacecraft into the Earth's atmosphere, where it will disintegrate. The payload has five Timepix (one particular version of the Medipix chip) radiation detectors in a cube-like arrangement, with four detectors orthogonally positioned facing outwards, and the fifth in the centre, facing outwards (relative to the centre of LUCID). Since the launch of LUCID the use of Timepix in space has since massively increased (e.g. VZLUSAT-1, which combined optics with Timepix to make an x-ray telescope, Baca et al., 2016), but LUCID remains the only instrument with a 3D configuration, permitting connecting tracks between different chips. The chips were surrounded by a 0.75mm thick aluminium dome which blocks intense light, plasma and low-energy charged particles.

Timepix are extremely high signal to noise particle detectors that are able to distinguish the particle type, energy, and angle of incidence of tracks, making them excellent for characterising diverse radiation environments. To analyse the data, the students developed a machine learning approach to classifying the particle tracks. The huge amounts of data meant that it was a very complex task to implement; the students used GridPP resources (generously supported by Queen Mary University of London and the UK GridPP Collaboration Board) to analyse the millions of frames and tens of millions of tracks produced by the experiment.

Once they had used their algorithm to classify the tracks, they were then able to do studies on the temporal and spatial dependence of the radiation field as function of particle type, energy etc. Figure 2 from their paper shows the number of particles detected over the Earth's surface for ∼4000 frames in August and September 2016 for electrons, with the South Atlantic Anomaly clearly visible.

Will Furnell (now an undergraduate at the University of Kent), lead author on the paper, says about the experience:

> *vjidsakvfnjvfjnfvnjvnjl*

CERN@school

LUCID is part of a larger multi-disciplinary suite of IRIS school projects and experiments using Medipix technology called 'CERN@school'. Ongoing projects within this framework include IRIS school student researchers analysing ISS Timepix data in the 'TimPix' project. TimPix was part of Mission Principia, a larger scheme of school and educational projects linked to British ESA Astronaut Tim Peake's trip to the ISS in 2015/2016. Students have also applied data reduction techniques developed for LUCID and Timpix to data from Medipix detectors in large particle physics experiments. For example student researchers have been involved with efforts to detect magnetic monopoles in the MoEDAL experiment, Pinfold, 2009, and observe the two-photon Breit-Wheeler process ("turning light into matter") for the first time at the Central Laser Facility, Pike et al., 2014, both using Timepix. Finally CERN@sea is a project that has deployed Medipix RasPix detectors on a wave propelled Unmanned Surface Vessel, 'AutoNaut'. All this data is shared using The Timepix Analysis Platform at School (TAPAS - a platform written and developed by W.Furnell) to allow secondary school student researchers across the UK to analyse and share the data that they gather using Timepix radiation detectors across all CERN@school projects, and additionally as a home for the particle count data from the LUCID experiment. The platform allows users to upload their own data taken with a Timepix detectors, or data which has been provided to them, such as the TimPix ISS radiation data. All of the LUCID data is downloadable from TAPAS.

CERN@school also puts real detectors in schools; CERN@school kits (Timepix detector, laptop and resources) are lent out for six week periods at a time and are used by more than a hundred schools every year. Guides provided by IRIS include "Sunny Spells and Solar Storms", "CERN@school Users' Guide", "CERN@school Curriculum Guide"', "TimPix Guide". These kits have been used for both novel tests of traditional classroom experiments (e.g. inverse square law Whyntie & Parker, 2013) as well as original science, for example the Radiation In Soil Experiment (RISE) which has measured the radiation in different geological samples across the UK and has been cited by the Institute of Physics as an exemplar of good practice in improving gender balance (Institute of Physics, 2017). One notable example of a student proposed and lead project - students wanted to investigate whether the radiation background count changed during the 20th May 2015 eclipse. Eighteen schools across the country took readings over the full duration of the partial eclipse and it was analysed by a student and written up as an Extended Project Qualification. It was for many schools the highlight of the eclipse event since clouds across most of the UK prevented observations!

Teachers often report the benefits of using the visualization ability of the Timepix detectors (see fig 3) and the modernity of the equipment. The principle for the GM tube was first invented by Hans Geiger in 1908 and developed with Walther Müller into the practical tube in 1928. This is still the practical approach for teaching radioactivity suggested by the Institute of Physics, but teachers can now complement this with the cutting-edge nature of a CERN@school kit. Experiments can be performed using CERN@school kits where the ability to actually see the tracks of ionizing particles makes the experiments relat-

Figure 1: TechDemoSat-1 being loaded onto the Soyuz, image credit SSTL.

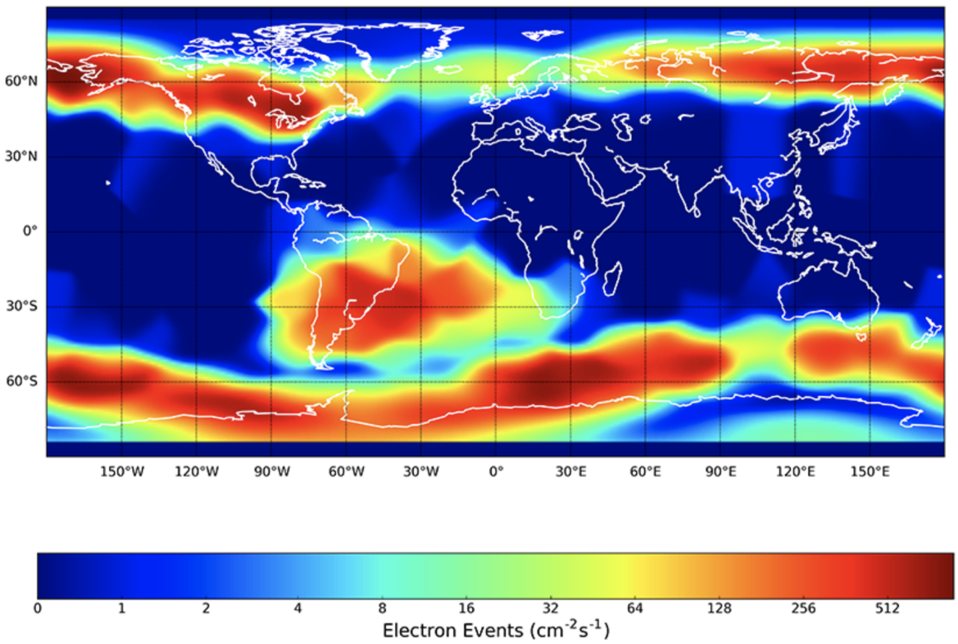

Figure 2: Map of electron flux, taken from Furnell et al., 2019, in press.

able and understandable at a whole new level. For example, experiments to show the effect of different absorbers on a radioactive source clearly distinguish between alpha, beta and gamma radiation with their characteristic tracks. The teaching of special relativity and time dilation can be enhanced by showing tracks of muons arriving in the chip and principles of imaging can be demonstrated with an alpha source. Experiments can be done to find the banana equivalent dose - where with a GM tube it can be difficult to show a significant difference to background with a banana, a Timepix chip can clearly show the beta particles both from a banana or a pile of low sodium salt, which also contains naturally occurring radioactive potassium. One of the most significant reactions to seeing radiation was from a physics teacher being introduced to the detector for the first time. Before going in to teaching he had been a submariner working on nuclear submarines for twenty years and seeing the nature of radiation displayed on the computer screen from the chip was incredibly illuminating and surprising to him - startling from someone who had worked close to radiation for most of his working life.

IRIS has run four CERN@school conferences; the first tied to the 10th Position Sensitive Detector Conference at the University of Surrey in September 2014, followed by a symposium at Queen Mary University of London, and two at the Rutherford Appleton Laboratory in the years following (see figure 4). Students have presented talks and posters at international conferences including Medipix collaboration meetings at CERN and National Astronomy Meetings in 2015 and 2016.

IRIS in Space

IRIS students have worked on a range of astrophysical projects beyond using Timepix. Students measuring galaxy clustering using VIDEO data from the VISTA telescope won a CREST Communication and Context prize and got to meet Helen Sharman. There is a project support by the Royal Astronomical Society to use Gaia data NEED MORE. There is a large project around preparing for the James Webb Space Telescope; students are working with Dr Olivia Jones at the UK Astronomy Technology Centre looking for dust in crystalline forms (space rubies and sapphires!) in Spitzer Space Telescope data. Students are also working on an earth observation project called MELT collaborating with Dr Anna Hogg at the Centre for Polar Observation and Modelling (CPOM, University of Leeds), looking at using satellite data to study the lifecycle of a glacier.

So far I have described only the space and astronomical projects; IRIS has projects in genomics with the Wellcome Genome Campus, finding 'baby Higgs' particles in LHC data with the University of Oxford, the links between biodiversity and mental health, zebrafish with the Department of Biomedical Science at the University of Sheffield, ionic liquids with UCL, and many more.

Many other organisations are also finding that real research in schools has a huge impact on developing transferable skills and the perception of science and researchers, Sousa-Silva et al. (2018). Original Research By Young Twinkle Students (ORBYTS) have contributed to published work on C_2H_2 rovibrational spectra (Chubb et al., 2018); so this new approach to science education is growing.

Conclusions

Collectively these projects demonstrate the capacity for real research projects in schools to enhance education and invigorate teaching - and that students really can contribute to scientific research. If you are interested getting involved with IRIS, do get in touch!

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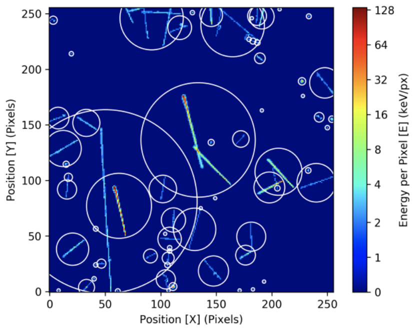

Figure 3: Example LUCID frame taken from Furnell et al., 2019, showing how Timepix helps the visualisation of radiation.

Figure 4: Photographs from the CERN@school Symposium, Rutherford Appleton Laboratory, 16th November 2017: a) Students presenting on the Radiation in Soil Experiment, b) Student presenting on the CERN@sea experiment, c) Abhishek Shenoy presenting on LUCID, d) Dr Chantal Nobs of CCFE presenting on her experiences

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